

## **Flexural Capacity of Reinforced Concrete Beams Strengthened Using GFRP Sheet after Fatigue Loading for Sustainable Construction**

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**Abstract.** Fiber reinforced polymer (FRP) has been applied not only for the simple structures but also for the advanced structures such as bridges or highway bridges for sustainable construction. In case of bridges or highway bridges, the structures experience not only static loadings but also fatigue loadings that may limited the serviceability of the bridge structures. In order to extend of the application of FRP on the such bridge structures to have a sustainable structures, the flexural capacity due to fatigue loading should be clarified. Glass composed FRP sheet namely Glass Fiber Reinforced Plastics (GFRP) is most commonly used due to its relatively lower cost compared to the other FRP materials. GFRP sheet is applied externally by bonding it on the concrete surface. Many studies have been done to investigate the flexural capacity of concrete beams strengthened using GFRP sheets. However, studies on the flexural capacity after fatigue loadings are still very rarely. This study presented the results of experimental investigation on the flexural capacity of the strengthened concrete beams after fatigue loadings. A series of concrete beams strengthened with GFRP sheet on extreme tension surface were prepared. Results indicated that after 800000 time of load cycle, the flexural capacity of beams specimens may decrease to only approximately 60%. The beam failed due to delaminating of GFRP sheet.

### **Introduction**

Sustainable construction is becoming a main concern of the many researchers. An innovative development has been introduced to achieve a sustainable construction. Fiber Reinforced Plastics (FRP) has been develop as one way to approach the goal of a sustainable construction. FRP has been accepted as a promising solution for corrosion problem of steel reinforcement. The development of FRP material available in the market are carbon based FRP (CFRP), glass based FRP (GFRP), and Aramid based FRP (AFRP), respectively. FRP material has been developed in many kind of forms such as rod, strand, strip, grid including rod equipped with U-anchor [1-3]. They are applied not only for new structures but also for retrofitting or strengthening of existing structures. Strengthening of deteriorated reinforced concrete structures using Fiber Reinforced Plastics (FRP) sheet material has also developed as an innovative alternative in the civil engineering fields. The FRP sheet is applied for strengthening on many field in civil engineering structures such strengthening of column, slab and beam of concrete structures buildings [4-8]. Fig.1 shows the application of CFRP in strengthening of reinforced concrete beams. The FRP sheet is applied simply by bonding it to the concrete surface. Therefore, the bonding capacity is a crucial matter in strengthening application.

The bonding of FRP sheet has been recognized as one of the essential problem occurred when it was applied on a structural member [3]. Fig.2 shows the GFRP sheet available in the market.

The application of FRP sheet for strengthening has been extended also for strengthening of bridge girders or piers. However, the application on the bridge structures need more specific investigation regarding to the fatigue load due to traffics loadings. As it has been investigated that, fatigue loading may cause the decreasing of structural performance and capacity after certain times of cycles. Fatigue

loading may increase the deflection or the strain of materials composed the structures even on the service load range [6]. In the worst condition, fatigue loading may cause a brittle failure of the structures. Therefore, the fatigue loading may determine the life of the structures.



Fig.1 Strengthening of Concrete beams using FRP Sheet



Fig.2 GFRP sheet (commercially available in the Market)

The increasing of the deflection on the reinforced concrete beams caused by the decreasing of the secant modulus of concrete due to creep as well as modulus of rupture of concrete. Creep strain in the compression zone under cyclic loading was noted as a main factor for the increased deflection of a reinforced concrete beams. The effective secant modulus of elasticity of concrete  $E_{e,N}$  may be accounted as [7]

$$E_{e,N} = \frac{S_{\max}}{\frac{S_{\max}}{E_c} + \epsilon_{c,N}} \quad (1)$$

Where  $N$  is the number of cycles,  $S_{\max}$  is the maximum compressive stress in concrete,  $E_c$  is the static modulus of elasticity of concrete and  $\epsilon_{c,N}$  is the cyclic creep strain in concrete which consist of a mean strain component resulting from the static mean stress and cyclic strain component which depend on stress range.

While the modulus of rupture of concrete may be predicted using [7] :

$$f_{r,N} = f_r \left( 1 - \frac{\log_{10} N}{10,954} \right) \quad (2)$$

Where  $f_{r,N}$  is the initial modulus of rupture of concrete, and  $f_r$  is the modulus of rupture of concrete after  $N$  cycles of loading.



However, on the concrete beams strengthened using GFRP sheet, the bonded GFRP plays an important role in the development of the flexural capacity. The research relating to the application of FRP is being intensively conducted all over the world to answer the questionable problem in the application of the FRP material [1,2,4]. However, a substantial amount of research related to flexural capacity of the strengthened beams using FRP sheet subjected to fatigue loads has not been widely conducted and published. To address these areas, the authors conducted an experimental investigation on the effect of fatigue loads to flexural capacity of RC beams strengthened using GFRP sheet. A series of reinforced concrete beams were prepared to be strengthened using GFRP sheet by simply bonded to the concrete surface. The specimens were loaded under four points bending cyclic loadings. Detail of specimens and test setup is explained in the follows sub-sections.

Specimens

The details of specimens are presented in the Fig.3. The cross section of beam specimen was 150 x 200 mm with the total length of 3300 mm. The specimens were reinforced using 2 D14 steel bars as tensile reinforcement. D10 steel shear reinforcement was applied on shear span of the beam with the space of 100 mm to avoid concrete failure or cracks on the shear span. Two D6 steel reinforcements were also attached on the compression side for easy installation only. Fresh normal concrete was prepared and casted for all specimens. The casted concrete beams were cured for 28 days by covering using a wet blanket before the application of the GFRP sheet. The cylinders as well as beam specimens for compression and rupture test were also prepared to determine the material properties of concrete. The material properties of the concrete used in this study is presented in Table 1. Compressive strength of concrete at 28 days was 25.3MPa with Young of Modulus of 23.8GPa. Rupture strength of concrete was 3.3MPa.

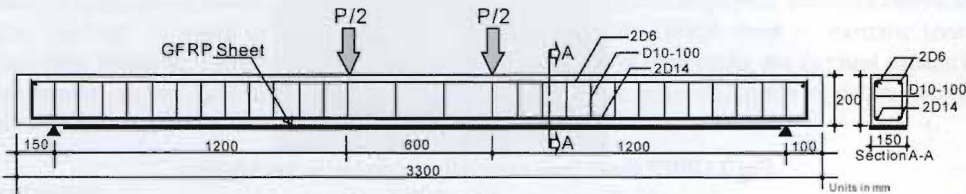


Fig.3 Detail of Specimens

Table 1.Properties of concrete

Cylinder test		Fracture test
Compression strength (MPa)	Elastic modulus (GPa)	Fracture strength (MPa)
25.3	23.8	3.3

Table 2 .Properties of GFRP Sheet

Properties	Value
Tensile strength in fiber direction	460 MPa
Ultimate strain	2.2%
Tensile modulus	20,90 GPa
Tensile stress on 90 <sup>0</sup> of fiber direction	20.7 MPa
Thickness of sheet	1.3 mm

Strengthening of beam specimens used the commercially available GFRP sheet with properties as shown in Table 2. The application was conducted based on the standard procedure of the manufacturer, as presented in Fig.4 [10]. Before the application of GFRP sheet, the bottom surfaces of the beams were smoothed by a disk sander. The epoxy resin was applied on the GFRP sheet placed on a table using a soft roller to impregnate all the fibers with resin. The epoxy resin was also applied on the treated surface before patching of the impregnated GFRP sheet to the treated surface. The patched GFRP sheet was positioned with the application of slight pressure using a soft roller. The beams were then cured again for 3 days to allow the hardening of resin.



Fig.4 Procedure of GFRP Application for beams strengthening

### Test Setup

Flexural tests were conducted using a flexural loading frame with capacity of 100 ton under four point bending test, as presented in Fig.5. The cyclic loading was applied using a computer controlled hydraulic jack. The load equal to 4 kN and the load at the 45% of the compressive strain of concrete were selected as lower and upper limit for the fatigue load ranges applied to the beams, respectively. The fatigue loading in the form of haiver sine wave pattern with frequency of 1.25 Hz was applied as illustrated in Fig.6. The load was applied using a hydraulic jack connected to the computerized control panel. Strain gauges were patched on the concrete surface and the GFRP sheet to monitor the response of those points due to applied load. Three LVDTs were also attached to measure the deflection of the specimens at the span center. Those instrumentations were connected to a data logger for data recording. The instrumented specimens were subjected to a four-point loading system.

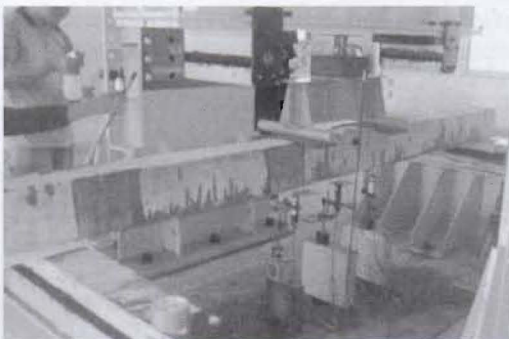


Fig.5 Setup of Beam Specimen



The measurements were conducted after predetermined number of load cycles as follows: 0, 1, 10, 100, 1000, 10000, 100000, 200000, 300000 and so on. The cyclic was limited to the 800000 time of cyclic. When the number of cycles reached each predetermined cyclic number, the machine automatically stopped for measurement. The measurement was conducted by loading the specimen manually up to 4 kN, 14 kN and 24 kN, respectively. The measurements were conducted on mid-span deflection, compressive strain of concrete at the span center, tensile strain of steel reinforcement and the strain of the GFRP sheet at span center, respectively. The cyclic loading was continued after measurement up to the target of cyclic number. It is noted here that flexural capacity of statically loaded control beams was 43.11 kN.

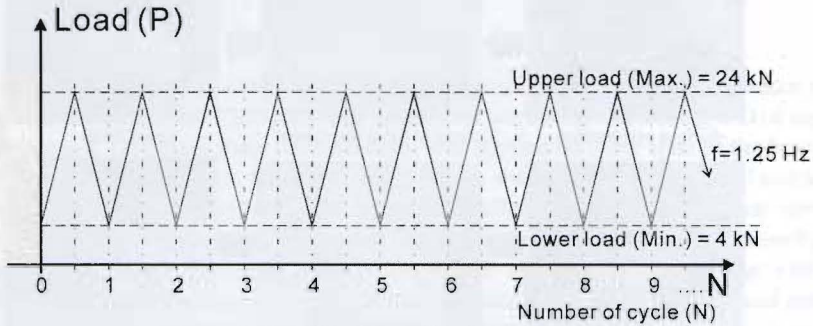


Fig.6 Cyclic Loading Pattern

## Test Setup

### Deflection of the specimens

Fig.7 shows the deflection of the specimens at lower and upper level of the load after cyclic loadings. The measurement of deflection was conducted at three level of loads which were 4 kN (lower level of cyclic load), 14 kN (mid level of cyclic load) and 24 kN (upper level of cyclic load), respectively.

As it can be observed that, the deflection increased as the increasing of the cycle number. This indicated that the beam specimen stiffness was decreased due to the cyclic loadings. At lower load, the decreasing of the stiffness or the increasing of deflection was smaller compared to the higher level of load. At lower load, the deflection increased approximately 0.6 mm after 800000 cycles of loads. At upper load ( $P=24$  kN), the deflection increased approximately 0.85 mm. The increasing of deflection was attributed to the relaxation of the materials composing the beam specimens

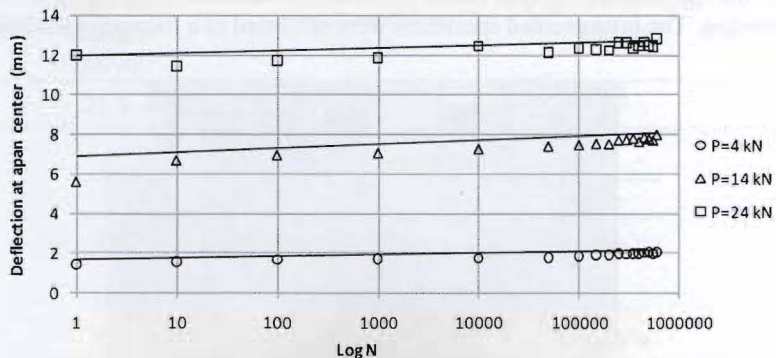


Fig. 7 Log-N Curve of the Deflection at span center

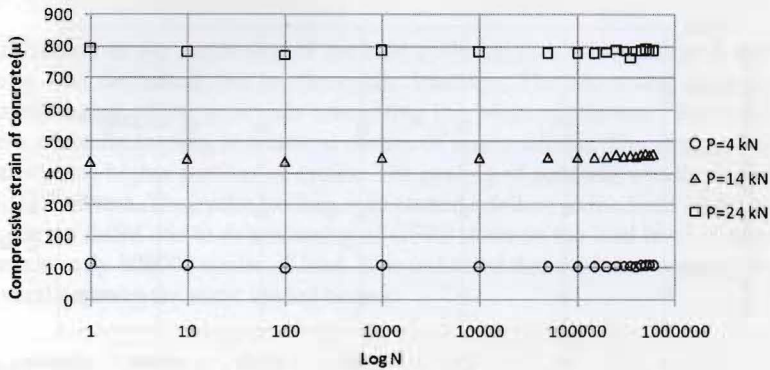


Fig. 8 Log N Curve of the compressive strain of concrete at span center

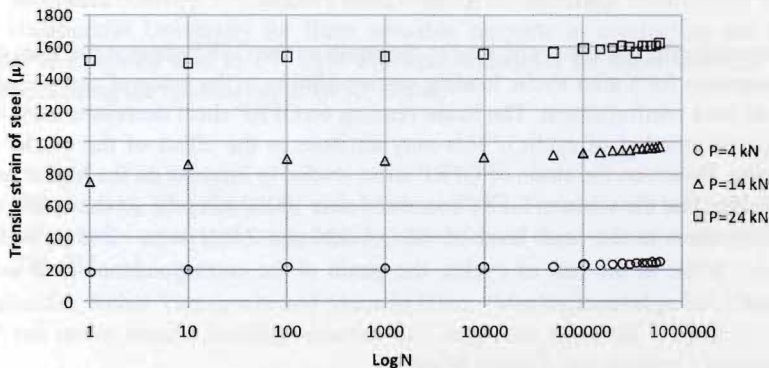


Fig.9 Log N Curve of the strain of tensile steel reinforcement

#### Log N-Strain Relationship

Fig.8 and Fig.9 presents the Log N curves of the strain on the compression concrete at span center and the strain on the tensile reinforcement, respectively. Measurement on the compressive strain of concrete presented in Fig.8 indicated that the strain was relatively constant. The cycle load did not influence significantly the concrete strain. At the beginning, the strain of concrete at  $P=4$  kN, 14 kN and 24 kN were  $115\mu$ ,  $435\mu$  and  $793\mu$ , respectively. At the end of cycle, the strain on correspondence loads was  $109\mu$ ,  $461\mu$ , and  $785\mu$ , respectively.

Strain measurement on the tensile reinforcement indicated that the strain increased as the increasing of the cycle number. The effect of the steel relaxation due to cycle load may be observed clearly at the 10000 – 1000000 scale of Log N curve. Relaxation of steel reinforcement due to cyclic loading is a natural matter of steel material. The cyclic loading may determine the fatigue life of the steel reinforced concrete. The cyclic of loading has more effect at upper load level ( $P=24$  kN and  $P=14$  kN ) compared to the lower level of load ( $P=4$  kN). At the beginning, the strain of steel reinforcement at  $P=4$  kN, 14 kN and 24 kN were  $184\mu$ ,  $754\mu$  and  $1516\mu$ , respectively. At the end of cycle, the strain on correspondence loads was  $245\mu$ ,  $962\mu$ , and  $1628\mu$ , respectively. At upper level, the relaxation strain was for approximately  $112\mu$ , while at the lower level, the relaxation strain was  $61\mu$ , respectively.



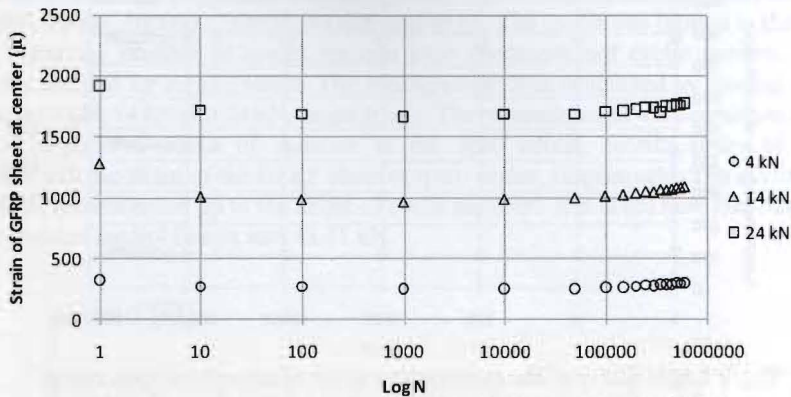


Fig.10 Log N Curve of the strain at the span center of GFRP sheet

Fig.10 shows the effect of the cyclic load to the strain on the GFRP sheet at the span center point. The strain propagation form after cyclic loading was un-similar to the strain of compressive concrete and the strain of steel reinforcement. The strain reading on GFRP sheet decreased until the 10000 cyclic numbers (small number of cyclic). This may attribute to the effect of the cracks on the constant moment zone. However, the strain of GFRP sheet tended to increase on the higher number of cycles. Fig 10 indicated that the strain of GFRP increased after 10000 of cycle. At the 10000 cycles, the strain of the GFRP sheet at the load level of 4kN, 14kN and 24kN were 245  $\mu$ , 982  $\mu$ , and 1687  $\mu$ , respectively. While at the end of cycles, the strain at the correspondence load level were 293  $\mu$ , 1077  $\mu$ , and 1761  $\mu$ , respectively.

#### (1) Flexural Capacity and Failure Mode

Fig. 11 shows the final failure of the beam specimen after approximately 800000 time of cycles. The beam failed due to delaminating of GFRP sheet on the load level of approximately 24 kN. This indicated that the beam capacity decreased to only 57% of flexural capacity the static loaded beams which was 43.11kN. It was noted that the peeling of concrete was the initiation of the delaminating of GFRP sheet. It should be noted here that the GFRP was applied simply by bonding them to the concrete surface without U-wrapping or GFRP belt. This was intentionally done to investigate the effect of the cyclic loading to the fatigue life of concrete beams strengthened with the GFRP sheet. The cracks at the constant moment zone initiated the local delaminating of GFRP, then finally caused a failure of the beams. This phenomenon has been reported that the flexural cracks may trig the local delaminating of GFRP or peeling of concrete cover [10,11].



Fig.11.Debonding Failure of GFRP Sheet

## Conclusions

The deflection increased as the increasing of the load cycle number. This indicated that the beam specimen stiffness was decreased due to the cyclic loadings. The increasing of deflection was attributed to the relaxation of the materials composing the beam specimens. Relaxation of steel reinforcement due to cyclic loading is a natural matter of steel material. The strain of GFRP sheet started to increase on the higher number of cycles. The peeling of concrete was the initiation of the delaminating of GFRP sheet. The cyclic loading may caused a failure in the form of delaminating of GFRP sheet. The beam failed due to delaminating of GFRP sheet on the load level of approximately 24 kN after approximately 800000 cycles of load. This indicated that the beam capacity decreased to only 57% of flexural capacity the static loaded beams.

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